Characterizing RTI Performance

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Overview

- Application of the RTI Performance Framework
- Defining RTI performance metrics
- Design of an RTI Performance Benchmark Suite

Measuring RTI Performance

- Motivation:
  - Want to be able to compare performance of various RTI implementations under various conditions
  - Want to be able to compare performance under HLA to performance of existing non-HLA distributed simulations (e.g. real-time using DIS)
- Key Problems
  - Which attributes of RTI performance are of interest
  - Common method (cross-platform, cross-RTI) for *measuring* RTI performance
  - Common method for *expressing* RTI performance

Experiment Methodology

- Testbed approach has been to design RTI experiments with an eye towards developing an RTI benchmark suite
- Some terms:
  - **Parameter** - A scheme or constant of the experiment *system* that cannot or will not be varied.
    - Examples: federate application, delivery type
  - **Condition** - A regime or situation of the experiment *environment* that cannot or will not be varied.
    - Examples: host time synch scheme, network topology
  - **Factor** - A condition or parameter that will be varied to measure its impact on performance
    - Examples: no. of objects per federate, no. of federates per federation

Experiment Methodology

- More Terms
  - **Regimes & Schemes** are mechanisms or functions
  - **Situations & Constants** are numerical or categorical quantities
  - **Performance Metrics -** used to express results of a test or experiment
    - Examples: percent CPU utilization, latency
  - Performance Metrics are used to determine
    - Benefits(e.g. HLA simulations use n% less network bandwidth than comparable DIS simulations)
    - Costs (e.g. HLA simulations use n% more CPU than comparable DIS simulations)

Example: Jager Scalability Tests Federation Characteristics

Characteristic	Value(s)
Simultaneous Federation Executions	1
Federates per Federation	2,4,6,8
Federates per host Objects per Federate	1 5,10
No. of Attributes per Object	1 Object Class, 7 Attrs/Object
Average Attribute Updates per Unit Time	N/A
Attribute Size No. of Parameters per Interaction	4 Bytes/Attribute Collision=3, Comm=1
Average Interactions per Unit Time	N/A
Parameter Size	4 Bytes/Parameter
Publish/Subscribe Topology	All-to-All

Example: Jager Scalability Tests
Test Environment Characteristics

Characteristic	Value(s)
Logging Software	HLA Testbed MOP Manager
Logging Software Configuration	Standard Config on All Feds
RTI Fedex Host	Fed A
RTI Exec Host	Fed A
Host Time Synchronization Mechanism	XNTP, Polling at 1 minute intervals
Non-Network Test Traffic	Kept to a minimum, but not a “clean” LAN

Example: Jager Scalability Tests
Performance Test Characteristics

Characteristic	Value(s)
Application	Jager
API Used	1.0
RTI Version	1.0R3
Delivery Type	Reliable
Federate Hardware	Sun Ultra 2
Federate OS	Solaris 2.5
Network	ATM LAN
CPU Utilization	Below Max
Test Duration	~200 sec
Time Mgt. Scheme	Not time constrained, not time regulating

Example: Jager Scalability Tests
RTI Services
(Table 1 of 2)

SERVICE	IF Ref	Srvcs Used		SERVICE	IF Ref	Srvc Used
Create Federation Execution	2.1	**X**		Delete Object	4.8	**X**
Destroy Federation Execution	2.2	**X**		Remove Object†	4.9	
Join Federation Execution	2.3	**X**		Change Attribute Transportation Type	4.10	
Resign Federation Execution	2.4	**X**		Change Attribute Order Type	4.11	
Request Pause	2.5			Change Interaction Transportation Type	4.12	
Initiate Pause†	2.6	**X**		Change Interaction Order Type	4.13	
Paused Achieved	2.7			Request Attribute Value Update	4.14	**X**
Request Resume	2.8			Provide Attribute Value Update†	4.15	**X**
Initiate Resume†	2.9	**X**		Retract	4.16	
Resume Achieved	2.10			Reflect Retract†	4.17	**X**
Request Federation Save	2.11			Request Attribute Ownership Divestiture	5.1	
Initiate Federate Save†	2.12	**X**		Request Attribute Ownership Assumption†	5.2	
Federation Save Begun	2.13			Attribute Ownership Divestiture Notification†	5.3	
Federation Save Achieved	2.14			Attribute Ownership Acquisition Notification†	5.4	

RTI Services
Jager Scalability Tests
(Table 2 of 2)

Request Restore	2.15			Request Attribute Ownership Acquisition	5.5	
Initiate Restore†	2.16	**X**		Request Attribute Ownership Release†	5.6	
Restore Achieved	2.17			Query Attribute Ownership	5.7	
Publish Object Class	3.1	**X**		Inform Attribute Ownership	5.8	
Subscribe Object Class Attributes	3.3	**X**		Is Attribute Owned by Federate	5.9	
Publish Interaction	3.2	**X**		Request Federation Time	6.1	
Subscribe Interaction	3.4	**X**		Request LBTS	6.2	
Control Updates†	3.5			Request Federate Time	6.3	**X**
Control Interactions†	3.6			Request Min Next Event Time	6.4	
Request ID	4.1	**X**		Set Lookahead	6.5	
Register Object	4.2	**X**		Request Lookahead	6.6	
Update Attribute Values	4.3	**X**		Time Advance Request	6.7	**X**
Discover Object†	4.4	**X**		Next Event Request	6.8	
Reflect Attribute Values†	4.5	**X**		Flush Queue Request	6.9	
Send Interaction	4.6	**X**		Time Advance Grant†	6.10	
Receive Interaction†	4.7	**X**				

Defining RTI Performance Metrics

- Some RTI performance metrics used by the HLA testbed
  - Message Latency
  - Message Throughput
  - Host performance
    - CPU utilization
    - Memory utilization
  - Network performance
    - bandwidth consumed
    - message loss/dropped packets
    - multicast group usage

Defining RTI Performance Metrics

- Performance metrics used to characterize an HLA federate
  - Services Used
  - Percent usage of each service (e.g. 50% reflect attribute values, 40% update attribute values, 2% publish, 2% subscribe, etc.)
- Note that performance metrics often vary by federate within a federation.

Defining RTI Performance Metrics

- Message latency
  - assume definition of message latency to be *time required for message to travel from RTI ambassador(sender) to federate ambassador(receiver)*. This includes RTI latency and network latency, and does not assume any particular delivery scheme.
  - look at mean, max, min, std dev, variance
  - varies depending on a variety of factors(see following).
    - Example: mean latency doubles for reliable vs. best effort delivery(UDP vs TCP).

RTI 1.0/Jager Latency Results
Reliable Communication

(Further Testing in Process)

No. of robot ships per federates	No. of federates	Latency Type	Mesgs Sent	Mesgs Rcvd	Mesg Loss %	Min. Latcy (usecs)	Max Latcy (usecs)	Avg Latcy (usecs)	Median Latency (usecs)	Avg. Updates /sec per federate (update Attr /sec, send inter /sec) *
5	**2**	**UPDATT->REFATT**	**23745**	**23745**	**0**	**11836**	**355813**	**101793**	**93682**	**88.43**
"	**4**	"	**127578**	**127578**	**0**	**1288**	**1368790**	**169428.1**	**159066**	**61.4**
"	**6**	"	**264017**	**264017**	**0**	**4646**	**1262551**	**224545.7**	**233817**	**49.97**
"	**8**	"	**368150**	**368150**	**0**	**10922**	**1212134**	**282038.9**	**332009**	**37.43**
"	**2**	**SNDINT->RCVINT**	**2**	**2**	**0**	**91922**	**94299**	**93110.5**	**93110**	**0.13**
"	**4**	"	**140**	**140**	**0**	**42777**	**352353**	**158193.5**	**121940**	**0.14**
"	**6**	"	**2395**	**2395**	**0**	**32702**	**639596**	**254162.3**	**261839**	**0.29**
"	**8**	"	**5513**	**5513**	**0**	**65530**	**1220349**	**382519.2**	**273467**	**0.98**
10	**2**	**UPDATT->REFATT**	**24105**	**24105**	**0**	**9018**	**453900**	**117415**	**98793**	**84.69**
"	**4**	"	**144569**	**144569**	**0**	**10525**	**695886**	**203507.1**	**207560**	**66.07**
"	**6**	"	**170029**	**170029**	**0**	**19845**	**845534**	**257741.1**	**253240**	**48.96**
"	**8**	"	**487722**	**487722**	**0**	**24546**	**2090181**	**343948.2**	**330854**	**41.35**
"	**2**	**SNDINT->RCVINT**	**13**	**13**	**0**	**36764**	**217338**	**101927.7**	**85286**	**0.6**
"	**4**	"	**453**	**453**	**0**	**34617**	**467592**	**212325.1**	**236990**	**0.08**
"	**6**	"	**1973**	**1973**	**0**	**59686**	**839476**	**307534.5**	**277876**	**1.4**
"	**8**	"	**6105**	**6105**	**0**	**72057**	**2128939**	**528402.1**	**311341**	**0.46**

* : Update Attribute rate decreases, and Reflect Attribute Value update rate increases as the number of federates Increase

RTI 1.0/Jager Latency Results
Best Effort Communication
(Testing in Process)

No. of robot ships per federates	No. of federates	Latency Type	Mesgs Sent	Mesgs Rcvd	Mesg Loss %	Min. Latcy (usecs)	Max Latcy (usecs)	Avg Latcy (usecs)	Median Latency (usecs)	Avg. Updates /sec per federate (update Attr /sec, send inter /sec)
5	**2**	**UPDATT->REFATT**								
"	**4**	"								
"	**6**	"								
"	**8**	"								
"	**2**	**SNDINT->RCVINT**								
"	**4**	"								
"	**6**	"								
"	**8**	"								
10	**2**	**UPDATT->REFATT**								
"	**4**	"								
"	**6**	"								
"	**8**	"								
"	**2**	**SNDINT->RCVINT**								
"	**4**	"								
"	**6**	"								
"	**8**	"								

Defining RTI Performance Metrics

- Message Throughput
  - Measured by finding no. of invocations per second for a particular HLA service
  - Update Attribute Values, Reflect Attribute Values, Send Interaction and Receive Interaction typically have the highest values of the services for this metric

RTI 1.0/Jager Throughput Results
Reliable Communications
(Testing in Process)

No. of robot ships per federates	No. of federates	Service Invocation	Average Throughput (invoc/sec)	Min Throughput (invoc/sec)	Max Throughput (invoc/sec)
5	**2**	**Upd Attr Vals**	**88.43**	**36**	**120**
“	**“**	**Refl Attr Vals**	**46.74**	**0**	**66**
“	**“**	**Send Interaction**	**0.13**	**0**	**3**
“	**“**	**Receive Interaction**	**0.01**	**0**	**1**
“	**4**	**Upd Attr Vals**	**61.4**	**24**	**95**
“	**“**	**Refl Attr Vals**	**149.57**	**40**	**209**
“	**“**	**Send Interaction**	**0.14**	**0**	**8**
“	**“**	**Receive Interaction**	**0.09**	**0**	**5**
“	**6**	**Upd Attr Vals**	**49.97**	**30**	**67**
“	**“**	**Refl Attr Vals**	**191.30**	**116**	**257**
“	**“**	**Send Interaction**	**0.29**	**0**	**19**
“	**“**	**Receive Interaction**	**2.41**	**0**	**106**
“	**8**	**Upd Attr Vals**	**37.43**	**4**	**54**
“	**“**	**Refl Attr Vals**	**228.56**	**0**	**301**
“	**“**	**Send Interaction**	**0.98**	**0**	**46**
“	**“**	**Receive Interaction**	**3.43**	**0**	**134**
10	**2**	**Upd Attr Vals**	**84.69**	**55**	**121**
“	**“**	**Refl Attr Vals**	**73.19**	**0**	**95**
“	**“**	**Send Interaction**	**0.6**	**0**	**2**
“	**“**	**Receive Interaction**	**0.08**	**0**	**5**
“	**4**	**Upd Attr Vals**	**66.07**	**24**	**87**
“	**“**	**Refl Attr Vals**	**166.83**	**75**	**235**
“	**“**	**Send Interaction**	**0.08**	**0**	**2**
“	**“**	**Receive Interaction**	**0.73**	**0**	**44**
“	**6**	**Upd Attr Vals**	**48.96**	**22**	**70**
“	**“**	**Refl Attr Vals**	**213.01**	**53**	**307**
“	**“**	**Send Interaction**	**1.40**	**0**	**66**
“	**“**	**Receive Interaction**	**1.23**	**0**	**47**
“	**8**	**Upd Attr Vals**	**41.35**	**11**	**66**
“	**“**	**Refl Attr Vals**	**229**	**103**	**326**
“	**“**	**Send Interaction**	**0.46**	**0**	**36**
“	**“**	**Receive Interaction**	**3.78**	**0**	**193**

RTI 1.0/Jager Throughput Results
Best Effort Communications
(Testing in Process)

No. of robot ships per federates	No. of federates	Service Invocation	Average Throughput (invoc/sec)	Min Throughput (invoc/sec)	Max Throughput (invoc/sec)
5	**2**	**Upd Attr Vals**			
“	**“**	**Refl Attr Vals**			
“	**“**	**Send Interaction**			
“	**“**	**Receive Interaction**			
“	**4**	**Upd Attr Vals**			
“	**“**	**Refl Attr Vals**			
“	**“**	**Send Interaction**			
“	**“**	**Receive Interaction**			
“	**6**	**Upd Attr Vals**			
“	**“**	**Refl Attr Vals**			
“	**“**	**Send Interaction**			
“	**“**	**Receive Interaction**			
“	**8**	**Upd Attr Vals**			
“	**“**	**Refl Attr Vals**			
“	**“**	**Send Interaction**			
“	**“**	**Receive Interaction**			
10	**2**	**Upd Attr Vals**			
“	**“**	**Refl Attr Vals**			
“	**“**	**Send Interaction**			
“	**“**	**Receive Interaction**			
“	**4**	**Upd Attr Vals**			
“	**“**	**Refl Attr Vals**			
“	**“**	**Send Interaction**			
“	**“**	**Receive Interaction**			
“	**6**	**Upd Attr Vals**			
“	**“**	**Refl Attr Vals**			
“	**“**	**Send Interaction**			
“	**“**	**Receive Interaction**			
“	**8**	**Upd Attr Vals**			
“	**“**	**Refl Attr Vals**			
“	**“**	**Send Interaction**			
“	**“**	**Receive Interaction**			

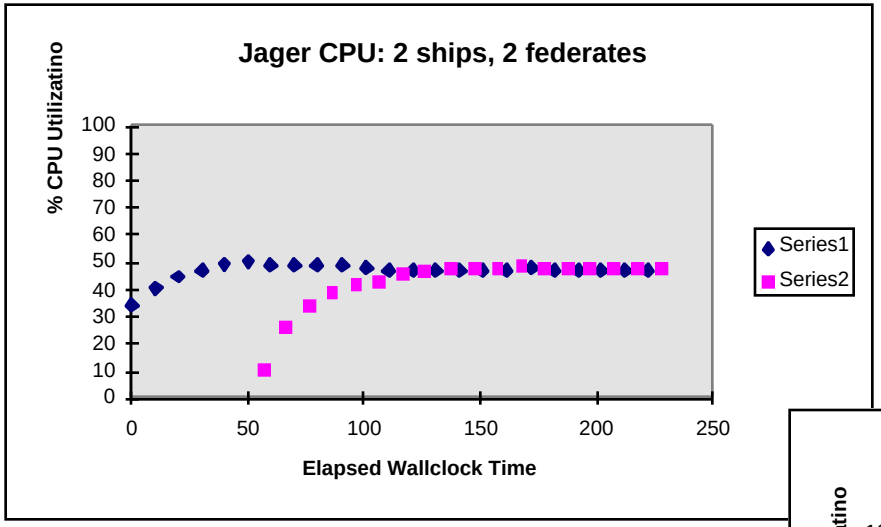
Defining RTI Performance Metrics

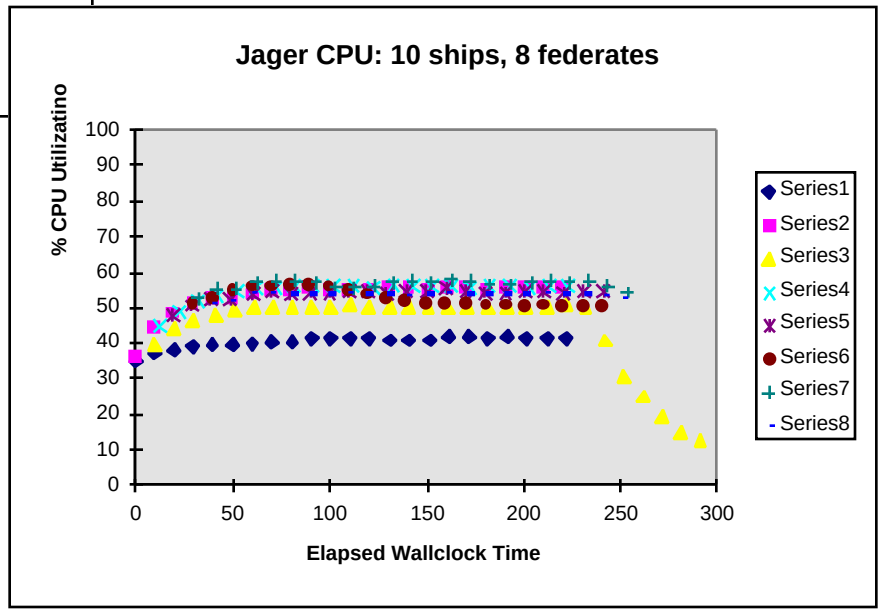
- CPU Utilization
  - % CPU utilization has been used for Sun platforms
- Memory Utilization
  - In KBytes
  - For RTI F.0/1.0, collect memory usage for
    - RTIExec process
    - Fedex process
    - Federate process

Backup Slides

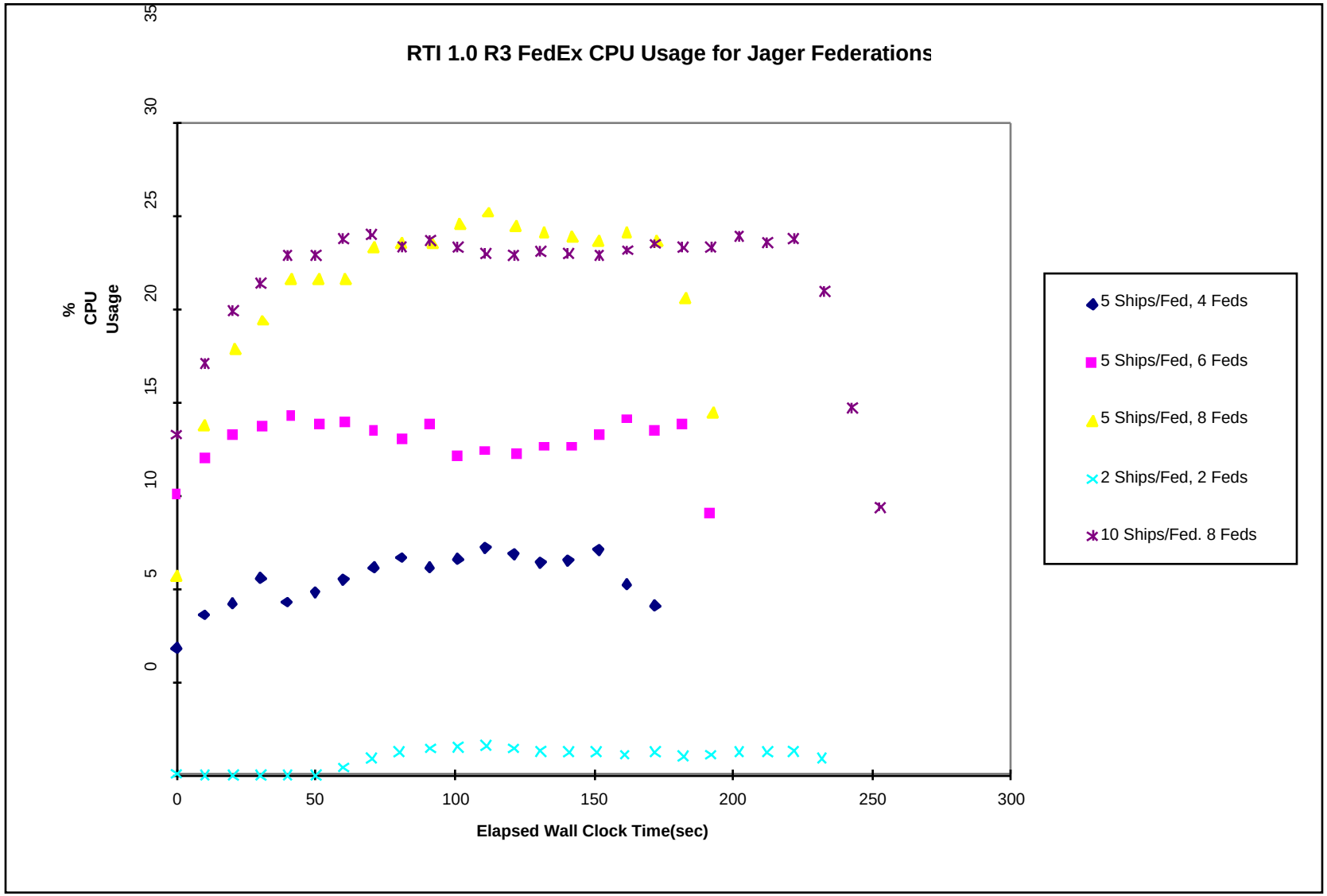
Slides removed from Briefing

Example: Jager CPU Usage

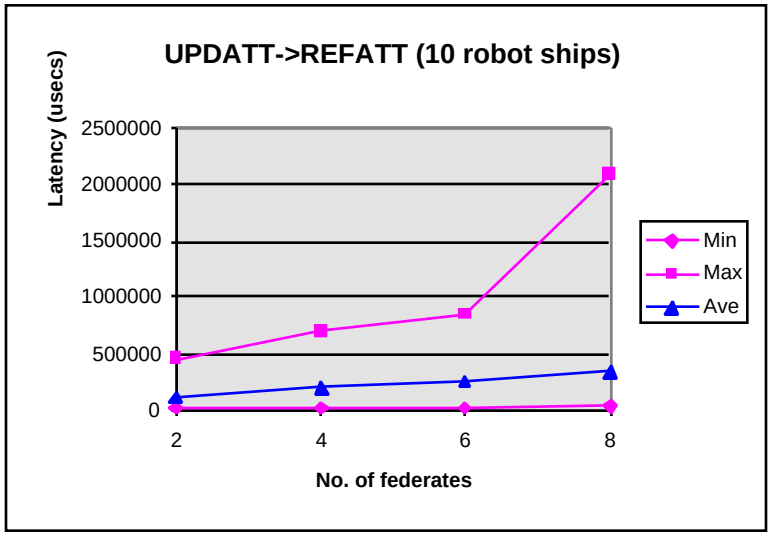


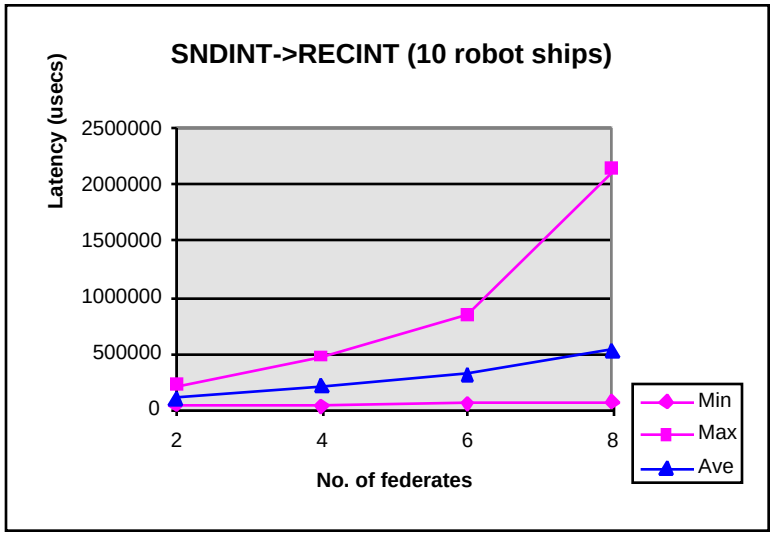


Example: Fedex CPU Usage

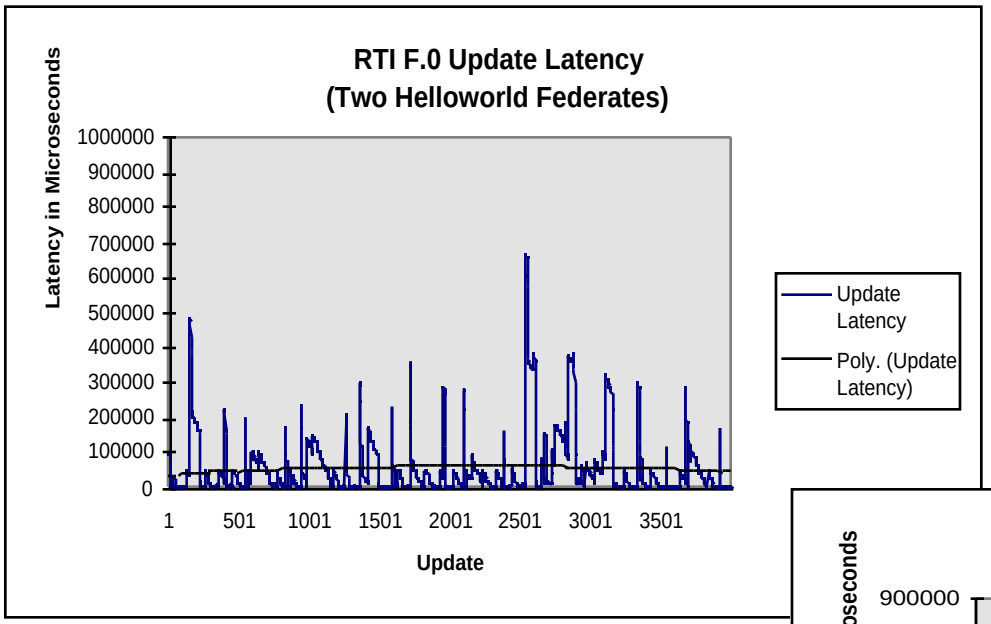


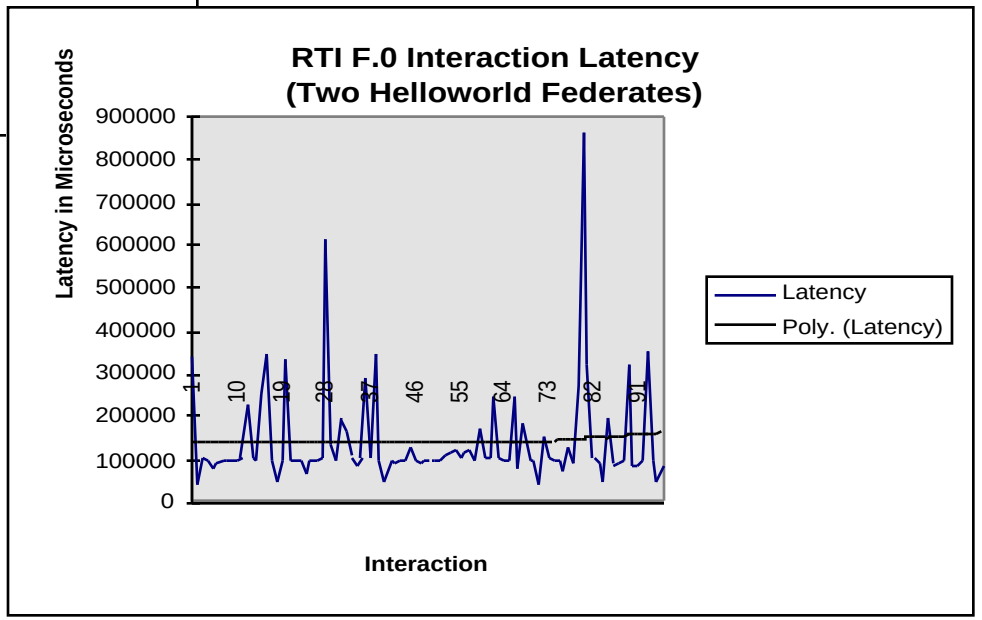
Example: Jager RTI Latency





Example: Update & Interaction Latency





Example: Jager Scalability Tests

Factor	Value(s)
Number of federates	2, 4, 6, 8
Number of robot ships per federate	5,10

Condition	Value(s)
Max Cpu Utilization	Below Max
Non-Test Network Traffic	Kept to a minimum, but not clean LAN
Measurement Software Measurement SW Config	HLA Testbed MOP Mgr Standard MOP.cfg
Host Time Synch Scheme	XNTP, Polling at 1 minute intervals
Federate OS	Solaris 2.5
Network	ATM LAN
Federate Hardware	Sun Ultra2’s only

Example: Jager Scalability Tests

Parameter	Value(s)
Federate Application	Jager
API used	1.0
RTI version	1.0R3
Delivery type	Reliable
Test duration	~200 sec
Time mgmt. scheme	Not time constrained, not time regulating
Simultaneous Federation Executions	1
Federates Per Host	1
No. of Attributes Per Object	1 object type, 7 attrs/obj
Avg. Attr Updates/Unit Time	N/A
Attribute Size	4 bytes/attribute
No. of Parameters/Interaction	collision=3, comm=1
Avg. Interactions/Unit Time	N/A
Parameter Size	4 bytes/parameter
Publish Subscribe Topology	All-to-all
RTI Exec Host	Fed A
Fed Ex Host	Fed A

Design of an RTI Benchmark Suite

- Needs to
  - measure nominal RTI performance
    - best case for defined performance metrics(number of objects, no. of federates, no. of attributes/object, latency)
    - use benchmark simulations (e.g. barebones RTI federations such as helloworld) on a “clean” LAN
  - measure practical RTI performance
    - above, in the presence of host and network background traffic
    - performance using a variety of real world simulations
    - using federations composed of heterogeneous platforms & RTI implementations

Design of an RTI Benchmark Suite

- Simulation community needs to choose a characteristic set of conditions under which RTI performance data is collected
  - no. of federates
  - network type
  - test simulation(s)
- This will allow comparisons between RTI implementations
- No single metric/simulation will adequately characterize RTI performance.

Design of an RTI Benchmark Suite

- Need to be able to relate to DIS
  - example: tolerable DIS latency defined as

"Acceptable transmission times for point-to-point communications from existing standards were compared to actual observed latency between network hosts.
Initial benchmarks were determined from the Communication Architecture Requirements (CAS) document Standard for Distributed Interactive Simulation draft 1278.2 IEEE [2], which provides details of acceptable latencies for given types of simulations. This standard was recently balloted and is currently undergoing a number of modifications. The CAS document indicates that crewed simulators have minimal latency tolerances between 100 to 300 milliseconds and computer-generated forces have a tolerance of 500 milliseconds. Latency sufficiency is the upper bound of acceptable time of travel for a PDU between a DIS transmitter and receiver entity. "

From "A Distributed Interactive Simulation Intranet
Using RAMP, a Reliable Adaptive Multicast Protocol"
(http://www.tasc.com/simweb/papers/disramp/latsuf.htm)

Example: Jager Scalability Tests

Federation Management Services	Create Federation Execution Destroy Federation Execution Initiate Federate Save Initiate Pause Initiate Restore Initiate Resume Join Federation Execution Resign Federation Execution
Declaration Management Services	Publish Object Class Publish Interaction Class Subscribe Object Class Attribute Subscribe Interaction Class
Object Management Services	Request ID Register Object Update Attribute Values Send Interaction Delete Object Request Class Attribute Value Update Discover Object Reflect Attribute Values Reflect Retraction Receive Interaction Provide Attribute Value Update
Time Management Services	Request Federate Time Time Advance Request
RTI Support Services	Get object Class Handle Get Interaction Class Handle Get Attribute Handle Get Parameter Handle Set Time Constrained Tick